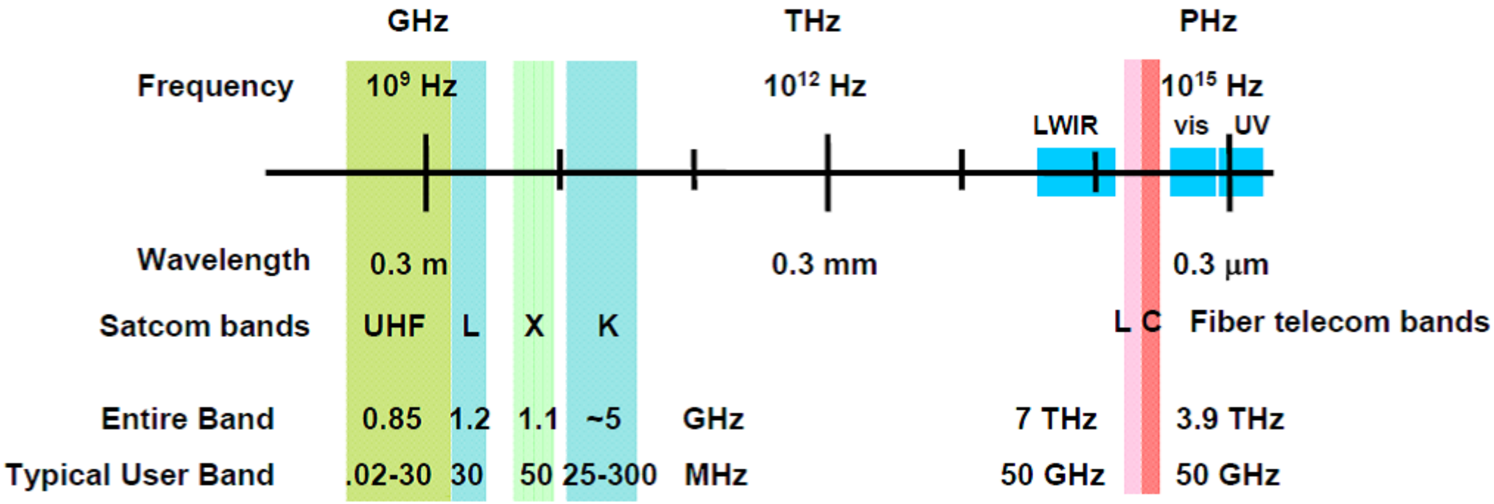
Benefits of Optical Communications



Features of extremely short wavelengths of IR light	System Potential	Improvement Over RF
Nearly infinite bandwidth (and fiber telecom components to make use of it)	- Extremely high data rates in unregulated bands - Use of extra bandwidth to achieve very high efficiency	10's of THz vs 50 GHz
Extremely high gain from small apertures	Very small terminals	Power delivery efficiency $10{,}000^2$ greater

High Rate for Deep Space
Garvin Science Study – Feb 2008

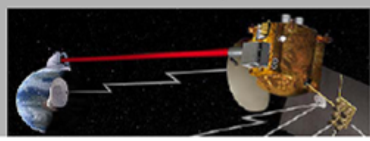
Ames Research Center

Lasercom for Planetary Sciences — *NASA's GSFC*

Scientific Drivers for Planetary Lasercom: Preliminary Findings

Dr. Jim Garvin
on behalf of the *ad hoc* GSFC Lasercom Science Analysis Team
and with Drs. Anne Kinney and Richard Vondrak (GSFC)

Friday, Feb. 29, 2008
Revised March 2, 2008



Enceladus Flagship Example
[via Dr. Amy Simon-Miller of GSFC/690]

Planetary Sciences Lasercom — *NASA's GSFC*

- Enceladus orbiter (Flagship) : near-global mapping
  - 1.5-m HGA, Ka-band downlink *(realistic baseline)*
    - 9 hr/day (minus eclipses), DSN: 70-m or equivalent
  - 1.85% science instrument data duty cycle is limit
    - Includes only Priority 1 instruments
      - Camera, RADAR, mass spectrometer are the data drivers
      - Assumes high on-board data compression
    - Drives mapping mission duration:
      - From 15 days to 811 days! (to get data back to Earth)
    - **Lasercom at 1 Mbps would allow for same data yield in 15 days**

→ New science if lasercom = monthly monitoring of dynamics of plume vent structure
→ + Potential monitoring of chemical variations associated with plumes over time

Feb. 29, 2008 — JBG-11

SIGNIFICANT FINDINGS

Planetary Sciences Lasercom — *NASA's GSFC*

- Lasercom data downlink rates *(1 Gbps at Moon, 0.1 Gbps at Venus/Mars, 1-10 Mbps for outer planets)* will fundamentally alter mission data collection and science strategies by providing greater flexibility and creativity for all types of data-intensive missions
  - Could eliminate "data starvation" scenarios which are typically required for monitoring or Outer Planet missions
- Lasercom will enable the potential for cm (or potentially mm) level ranging experiments to planetary surfaces and orbits, thereby providing orders of magnitude improvement in positional accuracy for geodynamical studies (involving gravity, topography, and forcings in the Solar System)
- Lasercom capabilities could fundamentally change Mars surface exploration strategies with mobility-intensive missions such as MER or MSL by changing the latency of decisions and providing never-before possible flexibility (relative to MER experience)
  - Rapid return of imaging required for planning and adaptation would avoid missing key features to study
- Lasercom capabilities will allow for GLOBAL scale sampling missions to outer planet moons, to Mars and to Venus that are not possible with current DSN capabilities, thereby increasing science and lowering risks associated with mission success
- Lasercom capabilities will allow Earth-style planetary remote sensing investigations (where they are justified), especially for dynamic systems such as planetary atmospheres and volatile reservoirs (ice sheets)
  - This is important for planets such as Venus and Mars, as well as Io (Jupiter), Titan and Enceladus (Saturn)
- In some cases, the lower mass and resource burdens made possible by lasercom could allow more mass for some classes of instruments that are usually "left off" due to mass allocations (i.e., surface geochem.)
- Intensive global mapping experiments (akin to the Earth Sciences LIST mission at any planet) are not presently possible given DSN upper limits on bandwidth but would be enabled if lasercom were available (i.e. for Mars, the Moon, or even Venus)

Feb. 29, 2008 — JBG-13

SUMMARY

Planetary Sciences Lasercom — *NASA's GSFC*

- Lasercom in planetary sciences is much more than "enabling" – it could revolutionize data collection and mission strategies across the Solar System, while reducing some risks
  - New science measurement capabilities and multi-temporal strategies
- Lasercom could develop into a Solar System precision ranging "tool" to drastically improve positional knowledge (and related science) for a great variety of objects (*just as DSN RF ranging has done for 40 years*), as well as dynamics
- Lasercom data downlink rates for Outer Planets could revolutionize the scientific yield from Flagship or New Frontiers class missions, while also reducing mission risks
- A pathfinding planetary target lasercom experiment is needed in the near-term to motivate development of this capability as a NASA-wide "tool" (*existence proof*)

Feb. 29, 2008 — JBG-15

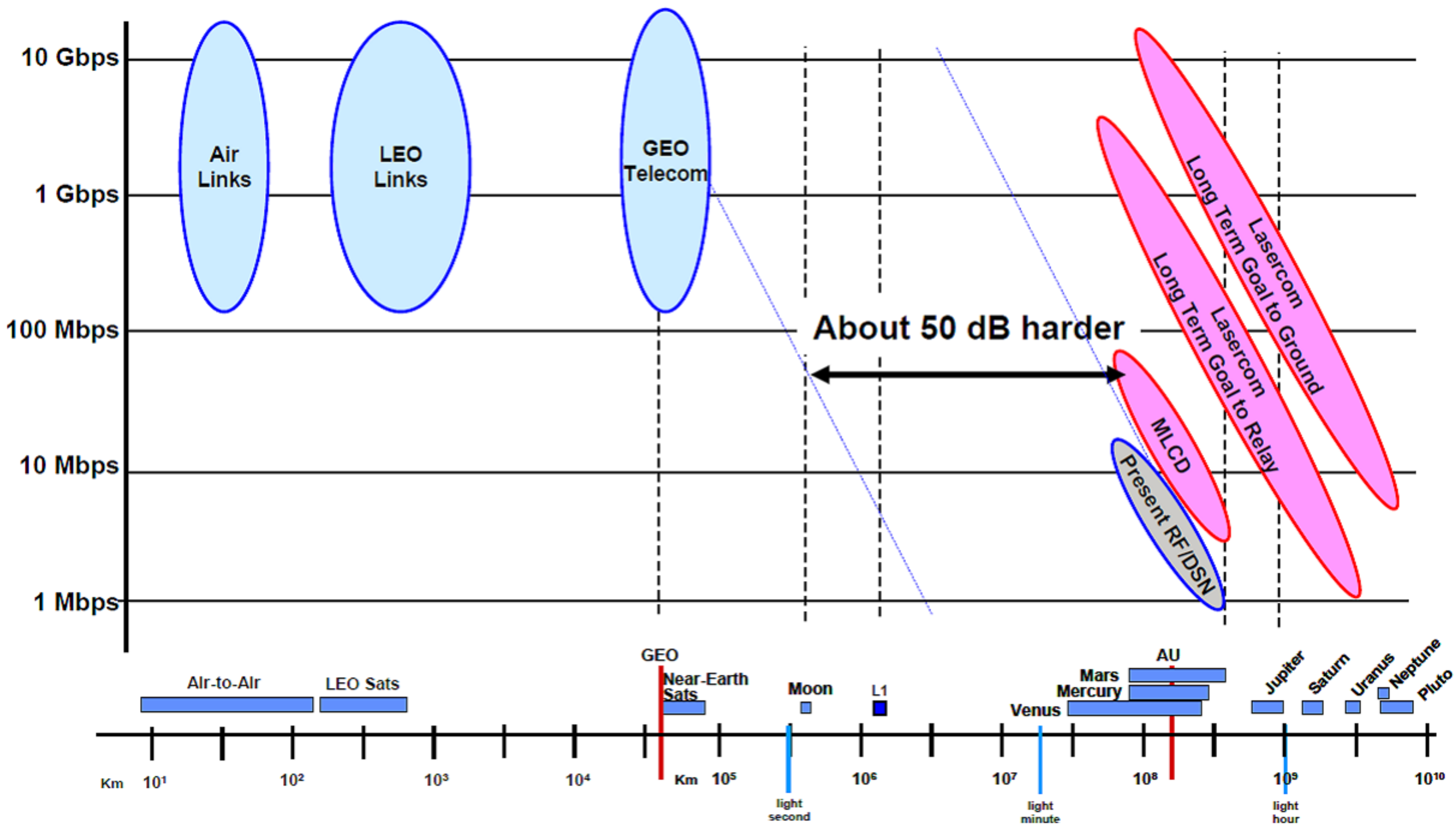
Observation:

50x rate improvement means

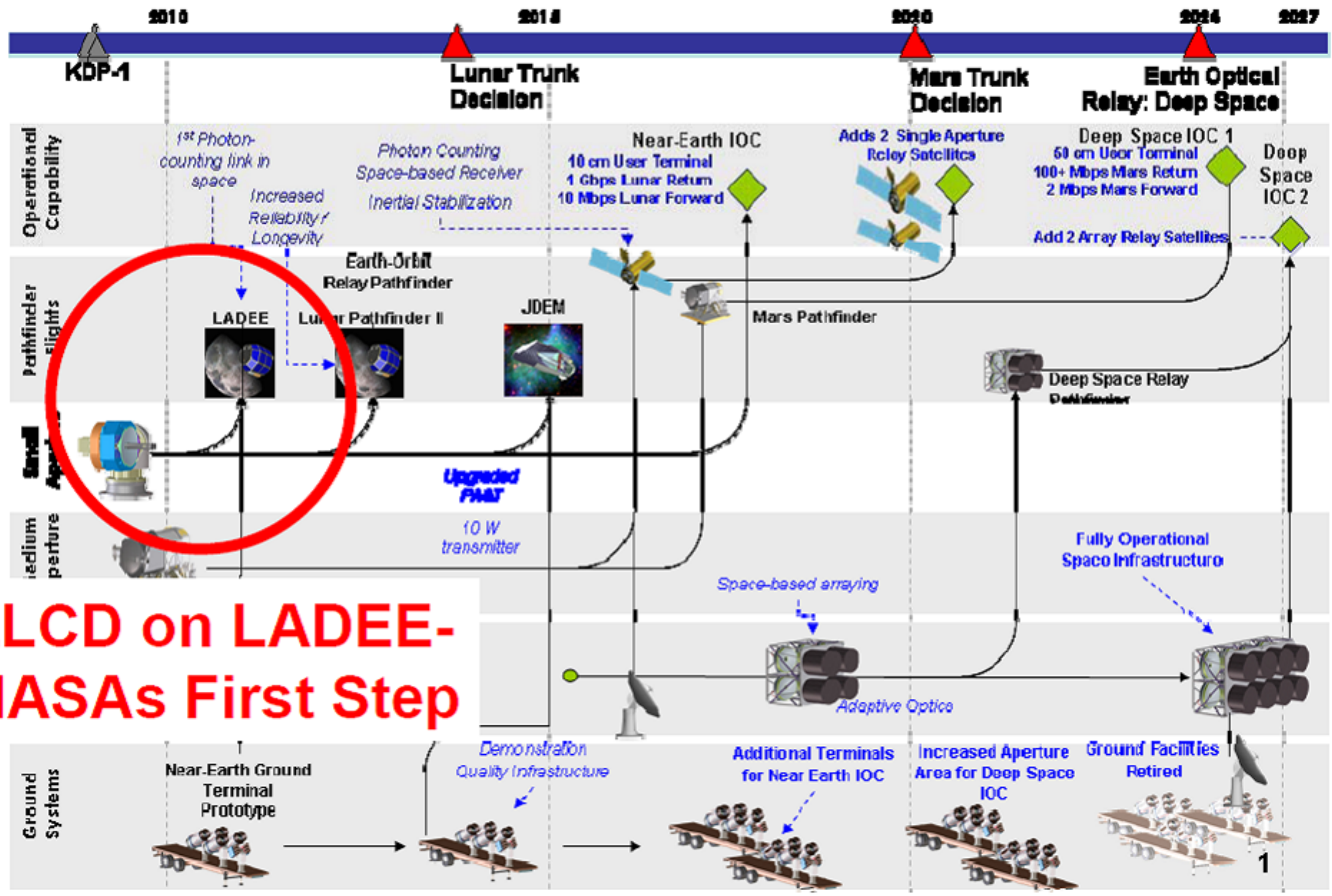
N year **mission might now be able to be done in**

N weeks

Wide Range of Lasercom Links



NASA Lasercom Strategic Plan
In Development



LLCD on LADEE- NASAs First Step

High-Level Goals of the *Tech Demo* LLCD

- Take first step toward making lasercom a reality for NASA science and exploration missions
- Perform detailed, integrated *design* for capable end-to-end system
  - Lasercom System Engineering
  - Flexible, low-SWaP space terminal that can be integrated onto spacecraft without adding many special needs
  - Inexpensive, high-efficiency ground terminal with scalable architecture
- *Demonstrate* many of the major functions required by future lasercom missions
  - Robust pointing, acquisition, tracking
  - Duplex comm day/night, full/new moon, high/low elevation, good/bad atmospherics
  - Time-of-flight measurements, as a by-product of the duplex comms, that could be built into a high-accuracy ranging system

LLCD Background

- LLCD is a Class D+ technology demonstration
  – Mission of opportunity on LADEE
  – No minimum operational duration for the LLCD instrument
  – Capability-based design
- LLCD development cannot be on the LADEE critical path
  – LLCD delivery schedule must be consistent with LADEE Integrated Master Schedule
- Operated on a non-interference basis
  – Science mission objectives have priority over LLCD
  – Program goal of 16 hours of mission operations
    - Spacecraft checkout (primary window: 30 days)
  – Primary science and post primary science operations phases used to the extent that spacecraft resources are available

LLCD Background (continued)

- History
  - March 2008: NASA HQ requested GSFC for LLCD proposal
  - Mid-June 2008: Decision to accommodate LLCD on LADEE
  - July 13, 2008: NASA Interagency Agreement with Air Force for MIT/Lincoln Laboratory tasking
  - June 2009: LLCD PDR

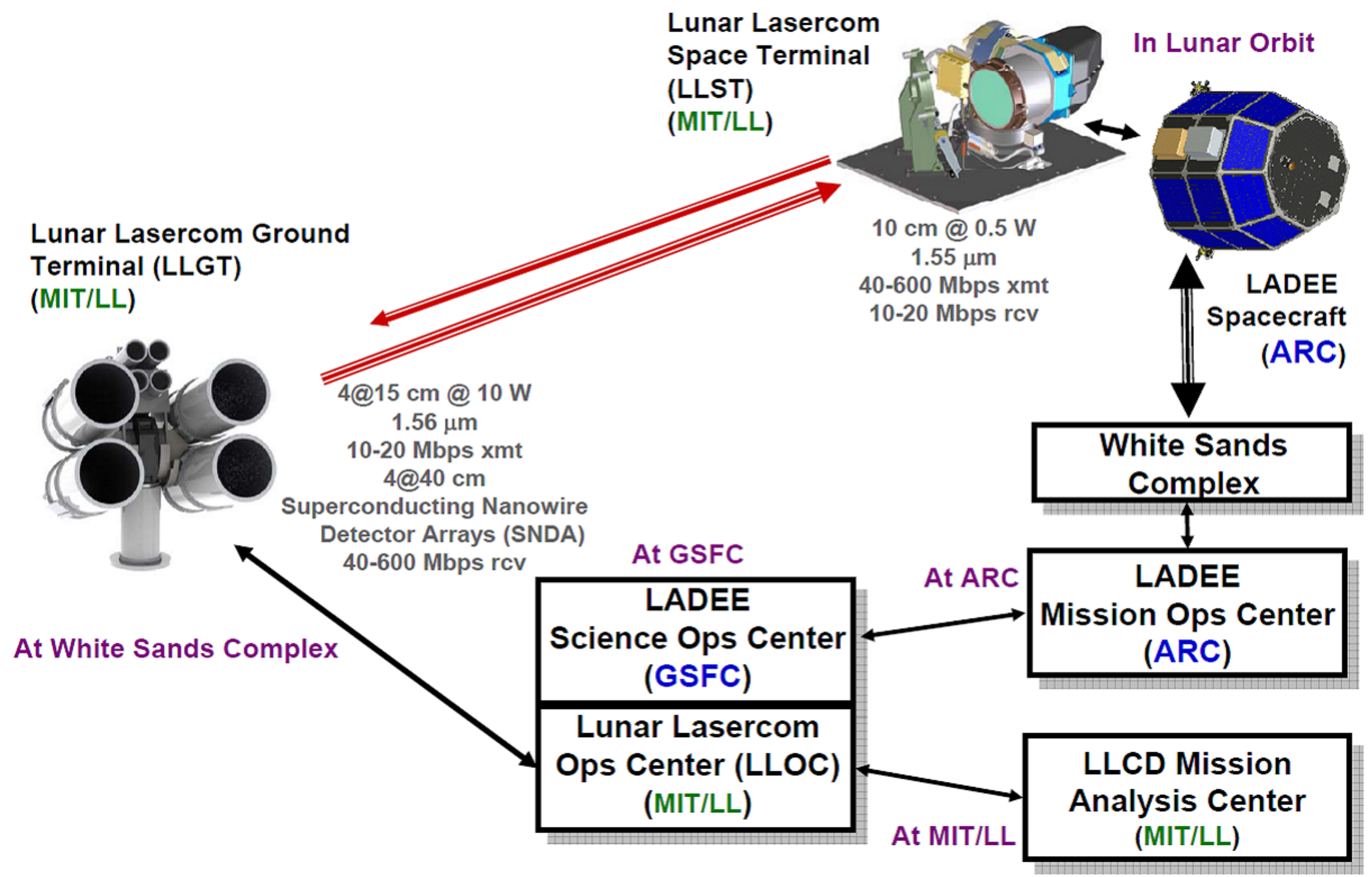
- Two Key LLCD Partnerships
  - NASA
    - NASA Headquarters-SCaN Program Office
    - NASA/GSFC-Project Office
  - MIT/LL is responsible for the development, test, and operations of the LLCD System

LLCD Overview

- Lunar Lasercom Space Terminal (LLST)
  - Launch Readiness: May 26, 2012
    - Minotaur IV+ launch vehicle
    - Wallops Island, VA launch site
  - Lunar orbit and commissioning
    - 1-month LLCD orbit at 200-250km
    - 3-months science orbit at 50km
  - Extended mission to extent possible

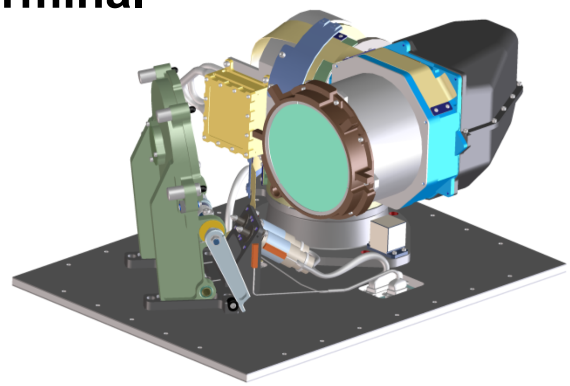
- Lunar Lasercom Ground Terminal (LLGT)
  - LLGT currently planned to be installed at the NASA White Sands Center (WSC) near Las Cruces, NM
  - Lunar Lasercom Ops Center (LLOC) will be installed at Goddard Space Flight Center
  - Lunar Lasercom Mission Analysis Center (LLMAC) will be installed at MIT Lincoln Laboratory in Lexington, MA

Lunar Laser Communication Demo System



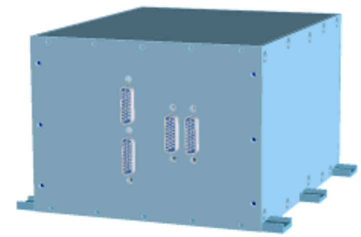
LLCD System Overview

Lunar Lasercom Space Terminal (LLST)



Optical Module

Modem Module



Controller Electronics Module

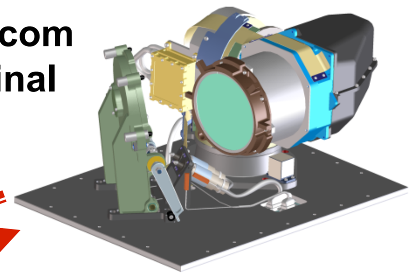
Lunar Lasercom Ground Terminal (LLGT)

Telescopes and Gimbals

Mobile Ground Terminal

LLCD Design Guidelines

Lunar Lasercom
Space Terminal
(LLST)



Lunar Lasercom
Ground Terminal
(LLGT)

- **LLST**
  - Base design on previously-developed 10-cm terminal
  - Keep simple without putting too much burden on LLGT
  - Make design largely useable by follow-on NASA projects such as operational Lunar or Lagrange
  - Keep size, weight, and power low
  - Migrate technology to deep space terminal

- **LLGT**
  - Base receiver design on Photon Counting Superconductor Nanowire Detector Arrays
  - Use array of 40 cm telescopes for receiver
  - Use array of 15 cm telescopes for beacon
  - Make design scalable to follow-on NASA projects
  - Keep eye safe
  - Simplify job for flight systems